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Functional Diseases of the Apple in Storage

By H. H. Plagge, T. J. Maney and B. S. Pickett

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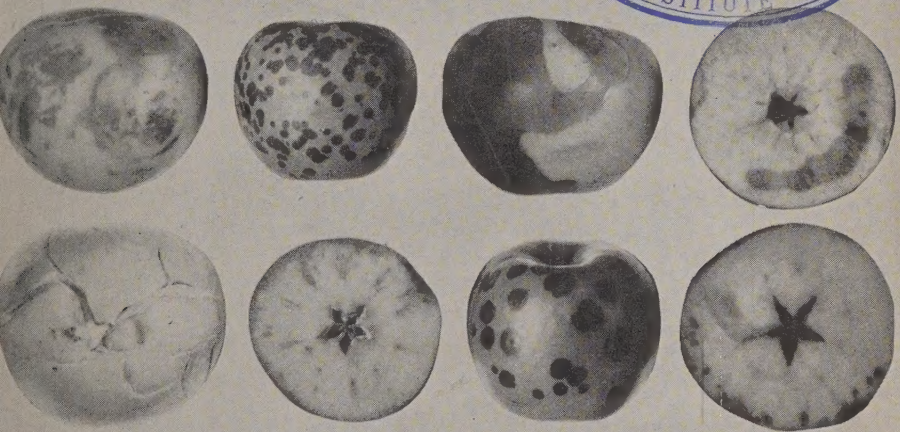

AGRICULTURAL EXPERIMENT STATION
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DIGEST

Functional, or non-parasitic, diseases of storage apples are frequently confused.

Apple scald, at one time the most troublesome storage disease, can be controlled with oiled paper. Proper maturity, low temperature, prompt storage and ventilation also are important in scald control. Some varieties scald more than others.

Jonathan spot is a skin disease readily controlled by storing immediately at low temperature. It is particularly troublesome on Jonathan.

Mealy and soggy breakdown, two kinds of breakdown, occur in storage apples. Mealy breakdown, which is characterized by mealiness and old age, may be postponed by proper handling and storing. Soggy breakdown is caused directly by low temperature. Soft scald is one type of soggy breakdown.

Brown heart results when apples are stored under conditions favoring the accumulation of carbon dioxide gas. Under usual storage practice the disease is of little importance.

Water core develops in fruit before it is picked. Recent investigations indicate that it is caused by high temperature in fruit while still on the tree.

Bitter pit is characterized by sunken spots on the surface of the apple. These spots extend into the flesh as brownish corky areas. The disease may occur on the fruit while it is on the tree, but makes most development in storage. Immature fruit is more susceptible than mature. Prompt low temperature storage checks its development.

Freezing injury is frequently confused with breakdown and other diseases. Frozen apples are easily injured and should never be handled or transported while in this condition.

Cork, drouth spot, York spot and crinkle are similar diseases characterized by dry corky areas which develop in apples on the tree.

Penicillium soft rot is a parasitic disease causing more apples to rot in storage than any other apple rot fungus. It is largely preventable by careful handling during picking and packing.

Storage results for 10 years show that apples keep better at temperatures of 35-36° F. than at temperatures of 31-32° F. Apples so stored develop better flavor and color, are not susceptible to soggy breakdown and are much more valuable on the market. Carelessly handled apples or those unprotected from scald by oiled paper, however, keep better when stored at 31-32° F.

Loss of moisture from apples is closely proportional to storage humidity.

Ripening proceeds rapidly at ordinary temperatures and slowly in cold storage. Prompt storage is necessary for long keeping. Each variety has a normal storage life for any given temperature.

Functional Diseases of the Apple in Storage[1]

By H. H. Plagge, T. J. Maney and B. S. Pickett

A systematic study of the storage diseases of apples includes the consideration of two general groups: (a) the functional, and (b) the parasitic diseases. Although most kinds of parasitic diseases are seldom found on good grades of apples, occasionally some of these escape inspection and develop considerably on ripe fruit in storage. The fruit grower who is concerned with producing sound fruit is familiar with such parasitic diseases as apple scab, apple blotch and cedar-apple rust. The fruit dealer, storage operator and consumer, on the other hand, more frequently come in contact with the functional diseases such as Jonathan spot, apple scald, bitter pit and breakdown.

The principal object of this publication is to describe and clearly point out differences between the various functional diseases of apples. Largely because of the lack of information about them, they have been the subject of much controversy and frequently the cause of litigation between orchardists, fruit dealers and storage operators.

The naming of functional diseases of apples has been based principally upon external and internal appearances, with little or no regard as to cause. Since some of these troubles have similarities, it is not surprising that the names of the diseases have been confused. The terms breakdown, browning, scalding, spotting and pitting, whether used correctly or not, do not indicate the cause of the disease, although they suggest the appearance. Observations and diagnoses of functional disturbances have not been complete, because a study of symptoms throughout the entire storage period has not always been made. Moreover, the timely diagnosis of the trouble, before other secondary parasitic or functional disorders become involved, is important in considering these diseases. In this publication, particular attention is given to those storage troubles

[1] Project 279, of the Iowa Agricultural Experiment Station.

which have been most frequently observed in the apple storage research work of the Pomology Subsection, as well as in the commercial storage industry. Because of the importance of these disturbances and the general lack of information about them, this bulletin presents descriptions, photographs of characteristic symptoms, brief accounts of conditions influencing the diseases and best methods of control.

APPLE SCALD

Apple scald for many years was regarded as the most troublesome and baffling storage disease of apples. The disease is non-parasitic and causes the skin of the apple to become brown. In its early development there is no appreciable softening or discoloration of the surface layers directly under the skin, but as the disease progresses the discolored areas become darker in color and there is then some discoloration and disfiguration of the fleshy portion. In late stages of development the factors causing scald result in the death of the skin, which is then readily separated from the pulp. The skin is then easily broken in handling the fruit and is no longer a protection against Penicillium soft rot and other apple rot fungi. This explains why severely scalded apples are usually affected with decay caused by soft rot.

A trace of scald not only detracts from the appearance of the fruit, but is likely to develop into severe scald a few days after the fruit is placed on the market. Apples apparently free from scald upon removal from cold storage may exhibit a brownish tinted appearance after 12 hours' exposure to ordinary room temperature, and a definite brownish and typical scalded appearance within 24 hours. With further exposure scald continues to develop on such fruit, so that in a few days it becomes severely scalded and may thus be practically unmarketable. (Fig. 1.)

Varieties differ markedly in susceptibility to scald. Because scald varies with degree of maturity and other factors, however, it is difficult to list varieties in their order of susceptibilty. If we assume that the varieties given below are picked when in prime condition, it is then possible to classify them. Susceptible varieties include Arkansas, Winesap, Stayman, Grimes, Ben

Fig. 1. Apple Scald. Mottled or blotched type of apple scald on Grimes. In this more common type of apple scald, considerable portions of the skin become brown. The browning may vary from a light cinnamon brown in early stages to a dark chocolate color in later stages. The entire skin of the apple may become involved.

Davis, Sheriff, York, Rome, Rhode Island Greening, Wagener and Baldwin. The varieties more resistant to scald include Jonathan, Delicious, Wealthy, Ralls, Willow, McIntosh, Edgewood, Golden Delicious, Northwestern Greening, King David and Fameuse.

Although scald has been one of the most troublesome storage diseases in the past, it is now possible to control or delay its appearance sufficiently so that it may no longer be a detrimental factor in the handling of apples. Brooks, Cooley and Fisher (1, 2) have worked out the most satisfactory method for controlling apple scald. These investigators showed that when apples are picked at the correct maturity, packed in oiled paper and placed directly in cold storage, scald can usually be controlled. Ventilation helped in scald prevention also, but the

use of oiled paper gave the most satisfactory control. (Fig. 2.)

To control scald successfully, maturity and storage temperature must be considered. When apples are harvested several days to a week too early they develop scald even though oiled wrappers are used. Scald will develop when the storage temperature is too high, although the conditions of maturity and packing in oiled paper are fulfilled. The results in table 1 show that a temperature of 50° F. is too high to prevent the development of apple scald on Grimes even though oiled wrappers are used. The apples were packed in boxes and one box was used in each temperature test.

TABLE 1. EFFECT OF DELAYING STORAGE (AFTER PICKING) ON APPLE SCALD DEVELOPMENT WHEN OILED WRAPS WERE USED. (STORAGE TEMPERATURE 50°F.; PICKING DATE SEPT. 25; INSPECTION DATE JAN. 25.)

Lot no.	No. of weeks of storage at 50°F. before placing in cold storage	Percentage of apple scald		
		30°F.	32°F.	36°F.
1	0	0.0	0.0	0.0
2	1	0.0	0.0	0.0
3	2	0.0	0.0	0.0
4	3	0.0	0.0	1.7
5	4	6.3	0.0	0.6
6	5	5.3	26.9	40.0
7	6	28.6	23.9	10.8
8	7	23.7	21.7	14.2
9	8	37.4	37.8	11.1
10	9	29.9	42.7	48.8
11	10	62.2	52.0	53.5
12	11	78.6	57.2	51.0
13	12	82.5	72.9	73.8

The effectiveness of oiled wrappers in the prevention of apple scald and the result of picking too early are shown in table 2. In this experiment the apples were packed in boxes, one box in each treatment. Fruit packed in oiled wrappers was free from scald in all cases except one, in which it was practically negligible. These data indicate that picking apples a week too early and that delaying storage may result in more scald. The table also indicates that it is particularly important to pack common storage apples in oiled paper.

Fig. 2. Above: Apple Scald. Entire surface of apples scalded.
Below: Apples free from scald. Scald was controlled by wrapping in oiled paper wrappers.

A comparison of the effectiveness of temperature in scald development is shown in table 3. In this experiment the fruit was wrapped in ordinary paper without oil. Two boxes of fruit were used in each test. The data show clearly that scald increased with the higher temperatures, and that apples under

TABLE 2. EFFECT OF OILED PAPER WRAPPERS, PICKING MATURITY AND DELAYED STORAGE ON APPLE SCALD ON GRIMES IN COLD STORAGE (32°F.).

(Condition Jan. 30, 4 days after removal from storage.)

Lot no.	Picking date	No. days delay before storing	Percentage of apple scald	
			oiled wraps	common wraps
1	Sept. 22	1	2.0	44.7
2	Sept. 22	7	0.0	5.8
3	Sept. 22	14	0.0	46.3
4	Sept. 29	1	0.0	0.8
5	Sept. 29	7	0.0	1.6
6	Sept. 29	14	0.0	16.0
7	Oct. 6	1	0.0	0.0
8	Oct. 6	7	0.0	0.5
9	Oct. 6	14	0.0	1.7
(Grimes in common storage (29°–60°F.)				
10	Sept. 29	1	0.0	60.2
11	Sept. 29	7	0.0	57.2
12	Sept. 29	14	0.0	77.7

TABLE 3. EFFECT OF STORAGE TEMPERATURE ON APPLE SCALD ON GRIMES IN ORDINARY PAPER WRAPPERS.

(Condition Jan. 24, 4 days after removal from storage.)

Lot no.	Storage temperature	No. days delay before storing	Percentage of apple scald
1	30°F.	1	0.0
2	30°F.	7	0.0
3	30°F.	14	0.0
4	32°F.	1	0.0
5	32°F.	7	0.5
6	32°F.	14	1.7
7	34°F.	1	11.1
8	34°F.	7	17.0
9	34°F.	14	10.6
10	36°F.	1	3.1
11	36°F.	7	15.9
12	36°F.	14	52.7
13	40°F.	1	45.8
14	40°F.	7	39.4
15	40°F.	14	74.9
Grimes in common storage (29°–60°F.)			
16	29° to 60°F.	1	60.2
17	29° to 60°F.	7	57.2
18	29° to 60°F.	14	77.7

air-cooled storage where the temperature was high early in the season, were particularly prone to develop apple scald. The results again show that delayed storage generally increased the susceptibility of the fruit to scald.

A large proportion of the apple crop is packed in barrels and baskets without being wrapped. Apples so handled should be packed with shredded oiled paper, which is the same as the oiled wrapping paper except that it has been cut up into narrow strips or ribbons. Many experiments have been carried out which show the efficiency of shredded oiled paper in scald control. The results given in table 4 are typical of the experiments which have been carried out by the writers. The fruit was packed in barrels. The method was found to be excellent for scald prevention.

TABLE 4. EFFECT OF SHREDDED OILED PAPER ON APPLE SCALD IN COLD STORAGE (32°F.).

(Condition 4 days after removal from storage.)

Variety	Picking date	No. days delay before storing	Percentage of apple scald	
			With shredded oiled paper	Without shredded oiled paper
Grimes	Oct. 6	4	0.5	19.4
Sheriff	Oct. 17	3	1.7	56.3
Arkansas	Oct. 17	3	15.6	69.5

Brooks, Cooley and Fisher's (1, 2) results with various oils and waxes suggested that the effectiveness of these materials as scald preventives was due mainly to their ability to absorb the odorous substances which are given off by ripe apples. This theory is now rather generally accepted. The additional cost of oiled paper is small; it adds to the attractiveness of the pack and tends to reduce bruising and skin breaks.

According to most experimental evidence and good commercial practice, it is considered that the following recommendations will give best results in apple scald control:

1. Pick fruit in a mature, prime, hard, ripe condition, when it begins to separate easily from the spur.

2. Grade, pack and store fruit immediately after picking.

3. Pack all varieties, whether susceptible to scald or not, in oiled paper wraps or shredded oiled paper before storing. This should be done as soon as possible after picking. The critical period in scald development is an interval immediately following picking.

4. The oiled paper used should contain from 15 to 20 percent of oil (based on original weight of the paper), which should be a special light, odorless and tasteless mineral oil.[2] Paraffined paper will not give the same results. One-half pound of shredded oiled paper should be used to each bushel of fruit, or 1½ pounds per barrel of fruit. The paper should be thoroughly mixed through the apples as the container is filled.

5. For best results, store apples in cold storage at a temperature of 35-36° F. promptly after picking and packing. When

[2] Properly treated paper is offered by the leading orchard supply concerns and paper manufacturers.

common storage is used, store and cool down the fruit as soon as possible. A moderately low temperature of 50° F. is considerably better than the usual prevailing packing house temperatures. It is therefore important to manage the common storage ventilating system judiciously. On warm autumn days do not open common storage rooms. Take advantage of cool mornings when placing fruit in storage.

JONATHAN SPOT

Jonathan spot is a skin disease which is particularly troublesome on the Jonathan apple. The blackish spots are confined to the apple skin, are usually circular, variable in size and range from minute spots the size of pin points to ⅜ inch or more in diameter. Typical Jonathan spots are 1/16 to 1/8 inch in diameter, black in color, and have a clear-cut border. (Fig. 3.) When fruit is removed from storage, however, the spots fade to a light brown. In storage, the spots increase in size, often become confluent and form irregular dark blotches over a considerable portion of the apple surface. The discolored skin spots, frequently though not necessarily, center or border around lenticels, especially when the fruit ripens rapidly under high temperatures. With this lenticel type the spots develop rapidly and frequently become slightly sunken as they become a source of infection for apple rot fungi. The latter type of spotting is often present on Jonathan stored in common storages but can be largely avoided by prompt storage at temperatures below 40° F.

From a commercial standpoint Jonathan spot is almost limited to the Jonathan. Although King David, Rome Beauty, Esopus, Wealthy and a few other varieties are sometimes affected, the disease on these is of less consequence than on Jonathan. In the apple breeding work of the Pomology Subsection it has been observed that some of the seedling apples resulting from crosses with either Jonathan or King David are frequently very susceptible to Jonathan spot. Jonathan is presumably one of the parents of King David. This indicates that Jonathan spot is an inherent disorder and is consequently more pronounced in some varieties than others.

Although the exact nature of Jonathan spot is not known,

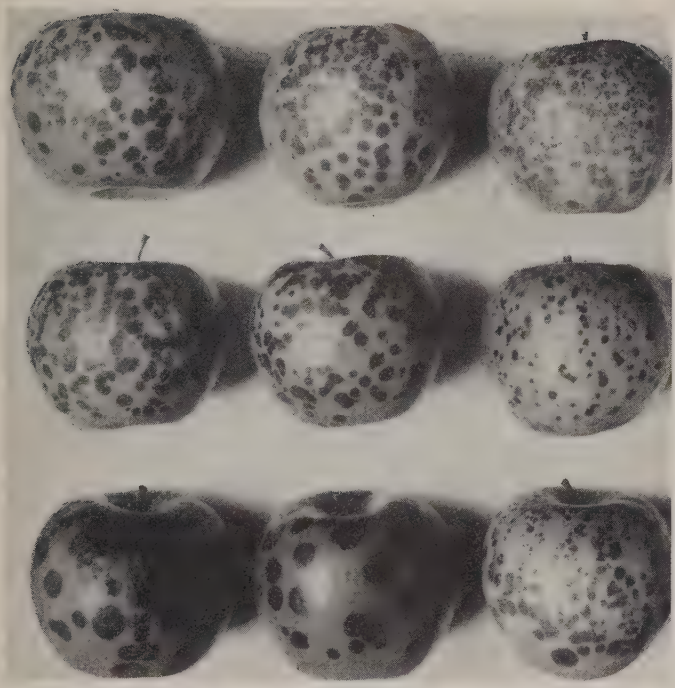

Fig. 3. Jonathan spot on Jonathan apples. Two general types of spotting are shown. One type centers and develops concentrically around lenticels; the other type occurs anywhere in the apple skin and is not necessarily restricted to lenticels. The two types are considered the same disease as they appear to be caused by the same conditions.

the evidence indicates that it is caused by an abnormal condition of the apple skin which is inherent in certain varieties. The spotted tissue results from a change in color of the skin pigment. Pentzer (12) found that the pulp cells immediately below the spots were lower in acidity than adjacent tissues. This seems to account for the change in color from red to bluish-black, since it is characteristic of anthocyanin pigment to change from red to blue as acidity decreases. Pentzer further showed that black spots are produced on apples in an atmosphere made alkaline with ammonium hydrate and that such spots soon disappear in the open atmosphere after the ammonia leaves the fruit. These observations suggest a difference in maturity

or state of senility between tissue directly below the spots and that below sound skin. Other evidence advanced by Plagge and Gerhardt (16) supports this explanation in that Jonathan apples stored immediately after picking which are relatively high in total acid develop less Jonathan spot than fruit which has had its acid content reduced by storing temporarily at high temperatures.

Because Jonathan spot is closely related to the color-bearing cells of the sub-epidermis, it follows that the highest colored fruit (and therefore the most desirable) is the most susceptible to the disease. Plagge and Maney (13) earlier pointed out that this spot disorder occurs more frequently and more intensely on the deeper colored specimens, while it makes much less development on poorly colored apples. Likewise, the more highly colored portion of the apple is more likely to develop Jonathan spot, which explains why the stem half of the fruit (which usually is better exposed to sunlight) develops more spot than the calyx half. (Fig. 4.) While the above generalizations hold in the majority of cases, a few well colored Jonathan apples in many storage lots appear to be immune to Jonathan spot.

The simplest and best way to prevent Jonathan spot is to store the fruit immediately after it is picked. The results of many storage experiments show that temperature is of primary importance in spot control and that postponing storage, after picking, considerably increases susceptibility. The results of experiments given in tables 5 and 6 show that delaying storage

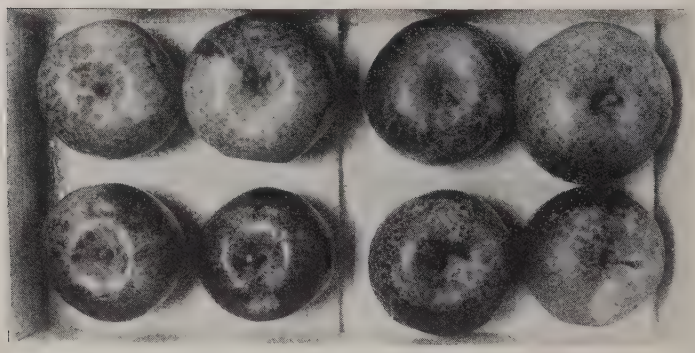

Fig. 4. Jonathan spot is more abundant on the stem half of the fruit. When the spots are confluent, dark blotches may be formed.

TABLE 5. RELATION OF MATURITY, DELAYED STORAGE AND TYPE OF STORAGE ON JONATHAN SPOT.

(Condition of fruit Jan. 23.)

Kind of storage	Date of picking	No. of boxes	Storage temp. F.	Percentage of "severe" spot in boxes*			
				Immed. storage	Delayed 7 days	Delayed 14 days	Delayed 21 days
Cold	Sept. 30	4	32°	2.9	2.0	17.1	57.0
Cold	Oct. 7	4	32°	2.3	2.0	33.7	29.3
Cold	Oct. 11	4	32°	15.1	21.3	19.2	36.8
Common	Sept. 30	1	35°-55°	53.2	46.8	42.8	40.0
Common	Oct. 7	1	35°-55°	28.0	14.3	55.7	32.0
Common	Oct. 11	1	35°-55°	34.9	43.3	38.3	40.0

*"Severe" spot includes apples with sufficient Jonathan spot to affect the commercial sale of the fruit. Specimens with less than 25 percent of the surface affected are not included under this heading.

2 or 3 weeks after picking increased the amount of spot. Late picking may also increase the tendency to spot, but the prevailing temperature will more likely be the deciding factor. The data in tables 5 and 6 also show common storage to be less effective in spot control than cold storage, which again emphasizes low temperature in spot control. When storage is carried out promptly after picking, temperatures 34° and 36° F. gave practically as good results as 30° and 32° F. Also, when apples were cold stored within a week of the picking date the degree

TABLE 6. EFFECT OF STORAGE TEMPERATURE ON JONATHAN SPOT.

(Condition on Jan. 18; apples packed in boxes.)

Lot no.	Date of picking	No. of days delayed	Percentage of apples having "severe" spot					
			Cold storage				Air-cooled storage	
			30°	32°	34°	36°	concrete underground storage	tile, cellar storage
1	Oct. 2	0	0.0	0.0	0.0	1.5	20.4	9.4
2	Oct. 2	7	0.0	0.7	0.6	2.4	24.9	25.0
3	Oct. 2	14	1.3	0.0	8.7	7.4	37.2	28.0
4	Oct. 2	21	9.2	2.0	21.2	22.3	40.8	22.6

of spot was of little importance, unless the picking date was abnormally late (table 5). Jonathan spot is readily controlled, then, with prompt storage at cold storage temperatures. Because of the prevailing high temperatures of common storages during the Jonathan picking season, control of Jonathan spot is more difficult with this type of storage than with cold storage.

It has been stated that Jonathan spot is best controlled by storing at proper temperatures promptly after picking. Other possible methods of control have been tried by the writers, but have not proved effective. Scald preventive methods, including oiled paper wraps, aerating or moving the storage room atmosphere and ventilating the containers, have not satisfactorily controlled Jonathan spot. Likewise, attempts to slow down and prevent acid changes in the apple skin by wrapping in paper impregnated with various acids have yielded disappointing results. Nitrogenous fertilizers have lessened the degree of spotting, largely, as they have decreased the amount of color on the fruit, but since good color is of major importance to the fruit grower this method also affords no practical application. For these reasons, the combination of low temperature with prompt storage must be applied in the control of Jonathan spot.

BREAKDOWN IN APPLES

The term breakdown has been used to include various types of disorders in apples, principally those which manifest considerable softening and discoloration of the pulp of the fruit. From our experimental studies and other evidence available, the following classification appears to serve as the best basis for differentiation: (1) Mealy breakdown and (2) soggy breakdown.

Mealy breakdown includes normally the type brought about by "old age" or senility in the fruit, whether induced prematurely by various agencies or not. Included in this category are Jonathan breakdown, breakdown following water core, bitter pit, scald, freezing injury, etc., but not softening and discoloration of tissue due to apple rot infection.

Soggy breakdown is the type which is brought about by storage temperatures that are low, but above the freezing temperature of the apple. It also includes the soft-scald type which occurs on Jonathan, Wealthy, Rome Beauty, Golden Delicious and Northwestern Greening.

MEALY BREAKDOWN

Mealy breakdown, as the name implies, is that type of functional disturbance in which the pulp tissue has changed from its normal firm, juicy condition to a soft, dry and crumbling one. It is usually found in fruit held too long in storage or at a too high storage temperature. Usually, the early stages of mealiness precede any brown discoloration of the flesh. Typical later stages of mealiness are frequently accompanied with bursting of the outer portions of the apple. The beginning or initial appearance of mealiness varies with varieties; for example, in Grimes, York and Delicious the early stages usually occur within the core or pith; in Jonathan and McIntosh early indications of this type of breakdown are observed as slight softening and browning of the pulp immediately under the skin.

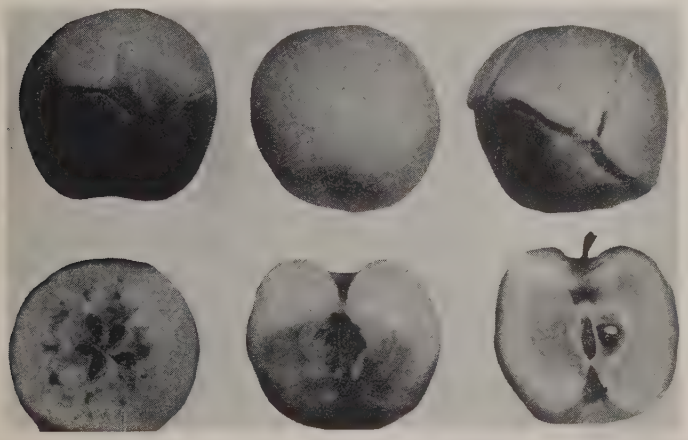

Fig. 5. Mealy breakdown in Grimes showing bursting of skin and outer portions. Sections of mealy breakdown apples are also shown. The apple in the center at the top shows no external discoloration, but exhibits other characteristics of mealy breakdown.

Fig. 6. Jonathan-breakdown type of mealy breakdown on Jonathan apples. Discoloration and mealiness typically begins near the skin and progresses toward the core. The two sections at the upper left show water core which has been followed with mealy breakdown. The dark colored tissues near the large vascular bundles are water cored.

(Figs 5, 6 and 8.) These descriptions, however, are for typical cases, as there are different agencies which may modify the appearance of mealy breakdown, thus making it difficult to generalize. Such disturbances as water core, bitter pit, apple scald, soggy breakdown and freezing injury may bring about a mealy condition prematurely or modify the appearance of mealy breakdown from the normal.

The breakdown known in certain districts as Jonathan breakdown is considered by the writers to come under the category of mealy breakdown, since it apparently is caused by certain climatic and orchard conditions and because there are locations where Jonathans are successfully grown which are practically immune to this trouble. (Fig. 6.)

Under normal conditions of growth and storage, mealy breakdown in winter varieties does not appear until very late in the storage period and may require a year or more in storage before complete breakdown sets in. In contrast, early fall varieties may break down early and this may be very evident in that the flesh crumbles and the fruit bursts while still on the tree. The time of appearance of mealy breakdown, then, depends on the inherent variety characteristics, as well as upon factors of storage and orchard conditions. Large fruit, especially oversize fruit, is more apt to become mealy than medium and small fruit.

In mealy breakdown different degrees of brown discoloration occur, due to oxidation of tissue exposed to the atmosphere. Discoloration accompanies, or soon follows, the soft mealy condition and may show externally or internally. Mealy apples develop brown discolored skins early and are prone to become affected with rot fungi, particularly Penicillium soft rot.

Fig. 7. Mealy breakdown on Grimes with apple rots starting in the cracks. Apples in this condition are soon destroyed by rots.

When bursting or cracking accompanies mealiness, rots soon invade the pulp of the apple. (Fig. 7.) Discoloration of tissue and rot infection, however, do not necessarily accompany mealiness.

Since mealy breakdown is primarily the result of senility, its occurrence cannot be postponed indefinitely. It need not be a factor in the storage of apples, however, when certain precautions in storage management are heeded. The principal precautions are: (1) Store fruit only when its storage capacity is adequate; (2) store promptly at correct temperature; (3) store only as long as the recognized period of storage for the variety.

SOGGY BREAKDOWN

The type of breakdown that frequently develops when apples are stored at cold storage temperatures, which are slightly above the freezing temperature of apples (29-34° F.), we have termed soggy breakdown. As the appearance of this disease varies with varieties and storage treatments, only typical cases will be described. When this breakdown is present in Grimes and Golden Delicious, the cortex portion becomes brown and soft, although this condition may not be visible externally. Viewed in cross section, the discolored portions vary considerably in size and number in different apples according to the severity of the disease. (Fig. 8.) Small brown lesions of the

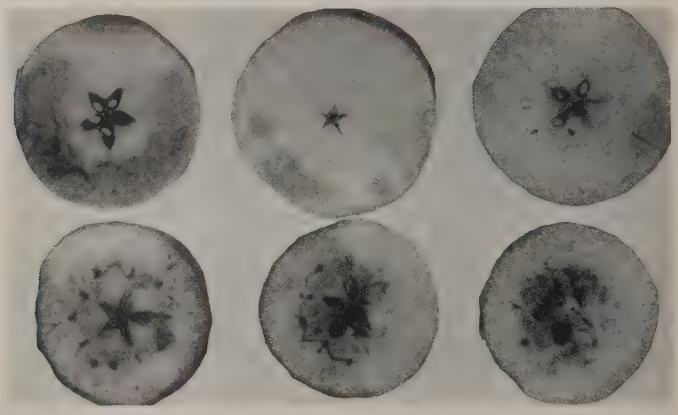

Fig. 8. Soggy breakdown and mealy breakdown of Grimes compared. Lower sections show mealy breakdown; upper, soggy breakdown. Different stages in severity of each disease are shown.

cortex may increase in size until a considerable portion or the entire cortex region is involved. In severe soggy breakdown a complete ring of soft, brown, spongy tissue is present, which is sharply defined from the remaining sound white core region. The latter seldom becomes affected. More typical cases appear to be sound macroscopically, having no skin discoloration because of the presence of a white zone of sound tissue immediately under the skin. Such specimens, however, have a characteristic dull appearance and a sponginess resulting from the underlying soft tissue which makes it easy for the experienced observer to detect the disease. External discoloration is evident when the broken down tissue comes in contact with the skin. (Fig. 9.)

When first removed from storage the breakdown tissue is soggy and watery, but with continued exposure to the atmosphere it becomes dry, and then the remaining sound tissue becomes mealy. With prolonged storage the soggy breakdown lesions lose moisture, become shrunken, corky and cause open pockets to develop within the pulp. Observations on this stage of soggy breakdown may have resulted in the origin of the term "flesh collapse" which has been used by McClelland and Tiller (9) in New Zealand.

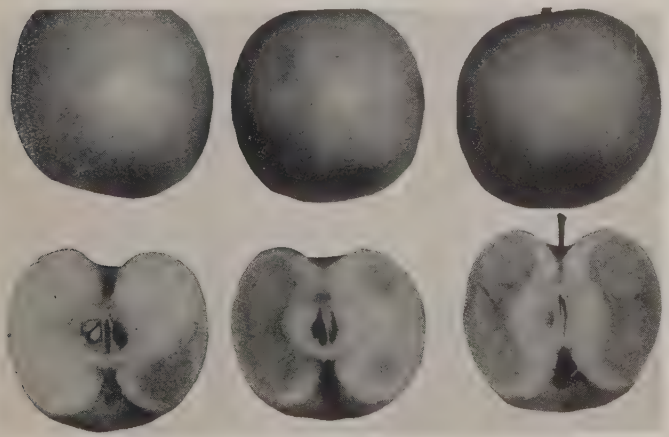

Fig. 9. Soggy breakdown on Grimes. The whole apples show no visible signs of the disease but are affected like those shown in sections below.

Apples with soggy breakdown have an alcoholic taste which is noticeable in both sound and broken-down tissue. It is present in fruit before there is any other discernible symptom and can be considered the first indication of the disease. Storage fruit appearing to be sound and having this taste will very soon develop other symptoms of the trouble. Soggy breakdown is clearly a low temperature disorder and makes practically no development at a temperature of 36° F. and higher.

The soft scald type of soggy breakdown occurs typically on the varieties Jonathan, Northwestern Greening, Rome Beauty, Wealthy and Golden Delicious. While this disease is generally known as "soft scald," the writers now believe that it is identical with soggy breakdown; and that the chief differences be-

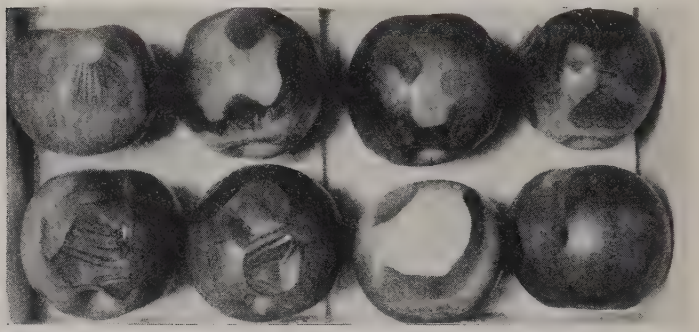

Fig. 10. Soft scald on Jonathan. The involved portions are frequently arranged in peculiar patterns.

tween soggy breakdown as described above (fig. 9) and typical "soft scald" as it occurs on Jonathan (fig. 10) lie in appearance only. The two types occur at the same time in identical apples as well as in similar fruit under like treatment in the varieties Golden Delicious, Winter Banana and Wealthy. (Fig. 23.) The cause of both types of the disease is a too low storage temperature. The term "soft scald" is misleading in that the disease is not related to apple scald and that it does not apply to the disorder earlier described as soggy breakdown (14, 15). For these reasons the two types have been considered under the same category.

In the soft scald type of soggy breakdown, lesions appear as light brown, elongated blemishes on the surface of the fruit.

These areas are typically curved, from ⅛ to ½ inch wide and from ⅛ to ¼ inch deep. They often partially or completely surround normal tissue, giving the appearance of island and peninsular formations (fig. 10). In the earliest stages, only the skin is discolored and the disease then resembles apple scald, in that the skin is brown and the underlying tissue is firm. This initial stage is of very short duration and is quickly followed by softening of the pulp tissue underneath. With still later degrees of development, black conspicuous spots of Alternaria (sp.) rots develop on the light brown tissue. The soft scald type of this breakdown develops early in the storage period; in Jonathan it appears between Nov. 15 and Jan. 1. The disease comes on rapidly, but when susceptible fruit is removed from storage, its development stops. The broken-down areas on the fruit make no further development after removal from storage, lose moisture rapidly, become corky and take on a sunken appearance. In this characteristic the soft scald lesions are similar to the soggy breakdown tissues in other varieties. The disease is plainly the result of low temperature storage, although other factors such as time of picking and delay before storing influence its development.

Soggy breakdown is of less importance in apples than apple scald, because it is limited to few important varieties. Those susceptible include Grimes Golden, Wealthy, Golden Delicious, Northwestern Greening, Jonathan, Rome Beauty and Winter Banana. While this list comprises the susceptible varieties thus far noted in the United States, certain English and Australian varieties are also susceptible to soggy breakdown and certain apple seedlings, notably crosses of Northwestern Greening by Wealthy, are susceptible. Varieties vary considerably in degree of susceptibility. Common sorts which appear to be free from the disease are Winesap, Stayman Winesap, Delicious, Willow Twig, York Imperial, Baldwin, Rhode Island Greening, McIntosh, Ben Davis, Fameuse, Sheriff and Arkansas. Others remain to be tested. During certain seasons and under certain conditions of storage, soggy breakdown causes considerable losses.

Two of the varieties which were found susceptible to soggy breakdown, Jonathan and Grimes Golden, have been regarded by the apple storage industry as unreliable storage apples, par-

ticularly unsafe for long holding. Investigations conducted at the Iowa Agricultural Experiment Station, however, have thrown light on the behavior of these varieties and a technique of handling them more successfully has been developed. Plagge and Maney (14) have shown that Grimes Golden and Jonathan may be held as late as Feb. 1, and even later, without unfavorable results.

Experiments in this country, as well as in England, Australia and Canada, have shown conclusively that the low temperature disease, soggy breakdown, is the result of storing at a temperature which is too low for the apple to complete its normal storage cycle. The results of one typical experiment are given. The data shown in table 7 indicate that soggy breakdown is best controlled by a temperature of 36° F. Storing at 30° and 32° F. resulted in large amounts of soggy breakdown when the fruit was previously stored at 50° F. for periods of 2 to 5 weeks. The fruit was packed in boxes, and one standard box of fruit was used in each test.

The experiment demonstrates the disastrous effects of delaying storage, even when temperature during the period of delay is comparatively low. Deferring the cold storage of the fruit at a temperature of 50° F. for weekly periods up to and includ-

TABLE 7. EFFECT OF STORAGE TEMPERATURE ON SOGGY BREAKDOWN ON GRIMES GOLDEN.

(Condition of fruit Jan. 25.)

No. weeks delay before cold storage	Percentage of soggy breakdown			Percentage of apple scald		
	30°F.	32°F.	36°F.	30°F.	32°F.	36°F.
0	3.8	0.4	0.4	0.0	0.0	0.0
1	0.8	6.5	0.6	0.0	0.0	0.0
2	67.8	73.5	4.0	0.0	0.0	0.0
3	60.3	67.9	8.7	0.0	0.0	1.7
4	63.4	69.3	21.4	6.3	0.0	0.6
5	68.5	38.0	8.1	5.3	26.9	40.0
6	0.7	3.5	0.0	28.6	23.9	10.8
7	0.6	0.0	0.0	23.7	21.7	14.2
8	0.0	0.0	0.0	37.4	37.8	11.1
9	0.0	0.0	0.0	29.9	42.7	48.8
10	0.0	0.0	0.0	62.2	52.0	53.5
11	0.0	0.0	0.0	78.6	57.2	51.0
12	0.0	0.0	0.0	82.5	72.9	73.8

ing 5 weeks made the fruit susceptible to soggy breakdown: while postponing cold storage of similar fruit for still longer periods resulted in a high proportion of scald. (Figs. 21 and 22.) The condition of the scalded fruit was poor. In addition to being scalded it was overripe and some apples were beginning to rot. We may conclude, therefore, that the storage temperature should be 36° F. rather than 30° or 32° F. and that prompt storage is essential for best results. Incidentally, the results give one explanation of why apples in common storage sometimes keep better than those in cold storage, since it is known that common storage temperatures in Iowa approximate 50° F. during the first 5 weeks of the Grimes storage season.

Experimental results with other varieties susceptible to soggy breakdown show also that storage temperature is of primary importance in the control of this trouble. The results with Jonathan for the season 1928-29, given in table 8, indicate again that storage temperature and the common practice of delaying apples before storing is of primary importance in the control of this disease. These results are comparable to those obtained with Grimes, in which a storage temperature of 36° F. and holding in common storage controlled the trouble. In this study the apples were packed in standard apple boxes.

TABLE 8. EFFECT OF STORAGE TEMPERATURE AND DELAYED STORAGE ON SOGGY BREAKDOWN ON JONATHAN. 1928-1929.

Picking date	Lot no.	No. days delay	Percentage of soggy breakdown				
			Temperature, degrees F.				Common storage
			30	32	34	36	
Oct. 2	1	0	8.2	1.8	0.0	0.0	0.0
Oct. 2	2	7	67.6	19.1	1.9	0.8	0.0
Oct. 2	3	14	21.7	16.2	5.1	0.9	0.0
Oct. 2	4	21	15.2	0.7	0.0	0.0	0.0

Soggy breakdown varies in severity from one year to another; that is, apples are more susceptible to the disease in some seasons than others. For this reason, less susceptible varieties such as Jonathan and Rome Beauty may not become affected in certain seasons, when susceptible varieties, such as Grimes and Northwestern Greening develop the disease. The reason for

the difference in susceptibility of the fruit from one season to another has not been definitely established, but it appears to be related to moisture and nutritional factors, since fruit taken from different orchards varies in susceptibility in the same season.

BROWN HEART

Another functional disease of apples, but of lesser importance, is brown heart. This disease is caused by the accumulation of the carbon dioxide gas from apples closely confined. In some respects it resembles breakdown, particularly the soggy type, and its description is therefore included in this publication.

Brown heart was first described by Kidd and West (8) of England, while they were investigating the possibility of storing apples in an atmosphere containing rather high concentrations of carbon dioxide. It was later found to cause considerable losses in commercial consignments of apples shipped from Australia to England. When apples are stored without adequate ventilation at rather high temperatures, a sufficient amount of carbon dioxide may be evolved by the fruit in respiration to bring about the disease, particularly when there is a subsequent lowering of the storage temperature. The carbon dioxide is more apt to be injurious at the cold storage temperatures usually employed, and widely fluctuating or uneven temperatures are conducive to its development. Brown heart may also be brought on by storage in rather tight compartments. The writers have produced brown heart artificially by coating apples with paraffin previous to placing them in storage (fig. 11).

Brown heart results in the browning and death of a part of the internal portion of the apple. In slight cases, small patches of brown tissue occur which are isolated, sharply defined and often numerous. These may occur anywhere within the apple and often appear to originate in the main vascular tissue. In severe cases a large portion of the internal part of the apple becomes involved, while the outer tissues may appear normal (fig. 24).

Apparently brown heart is of little importance in commerce, except when apples are stored in closely confined quarters, such as in ship holds. The disease has received little attention by

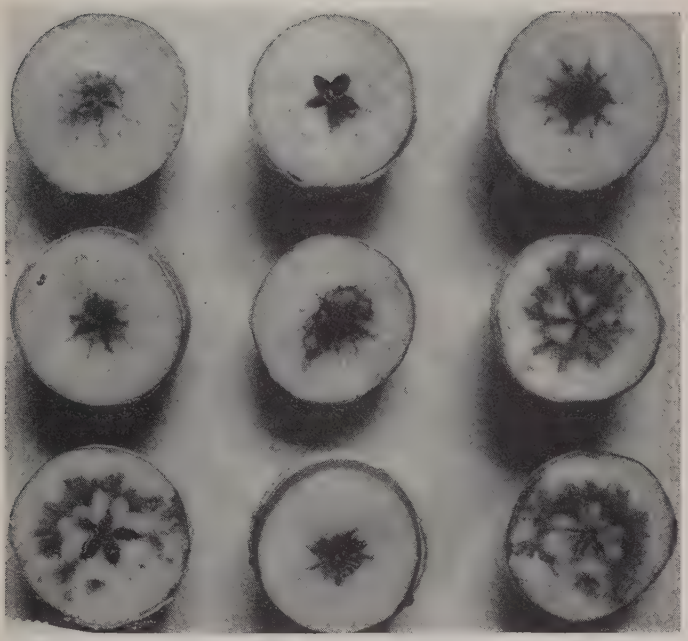

Fig. 11. Brown heart of Grimes Golden apples, produced by coating fruit with soft paraffin and storing at 50° F. Duration of treatment, 3 weeks. Caused by an accumulation of carbon dioxide within the tissue. Note tendency to start near core region, and irregular outline of the discolored tissue.

investigators in America, and although conditions for its development probably are not often obtained, nevertheless there is some possibility that it has been confused with other disorders.

INTERNAL BROWNING

Internal browning is the term specifically applied to a nonparasitic disease largely confined to Yellow Newtown. When grown in the Pajaro Valley of California, this variety is peculiarly susceptible to the disease. Although the disorder occurs on other varieties and on Yellow Newtown from other states, it appears to be of economic importance only in the California district (Overholser et al., 11). Like soggy breakdown, it is practically limited to cold storage temperatures below 36° F. Cross sections of diseased apples reveal the affected tissues to be firm and to be in somewhat elongated areas radiat-

ing outward from the core (fig. 12). In contrast to soggy breakdown, the tissue of which is soft, internal browning tissue is firm and frequently appears only in the core region. The two diseases are distinct, although they occur at similar temperatures.

The term internal browning is sometimes applied to the browning of tissue which frequently occurs with early stages of mealy breakdown in apples. The term internal browning is specific, however, since the disease is largely limited to one variety and certain apple districts. It is of no importance in Iowa. The two diseases should not be confused.

Fig. 12. Internal browning of Yellow Newtown apples. Affected areas are firm and radiate outward from the core. Controlled by storing at 36° F. or above.

WATER CORE

Water core is an orchard trouble which develops rapidly in fruit on the tree, especially during ripening. The disease is distinguished from others by the glassy, watery and hard appearance of the flesh. (Fig. 13.) In severe cases, when a considerable portion of the apple is affected, the disease is visible externally, although water cored tissue may be deep seated and segregated near the core and main vascular bundles. (Fig. 6.) Many varieties are subject to water core, among them Jonathan, Delicious, Winesap, Stayman Winesap, Northwestern Greening, Grimes Golden and Arkansas. Ordinarily the trouble is

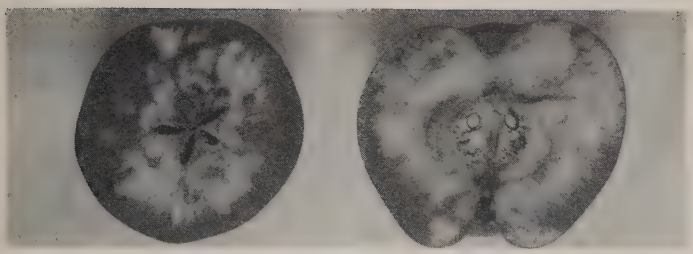

Fig. 13. Water core on Delicious apple. The outer portion of the fruit is hard and glassy in appearance.

commoner under irrigation than elsewhere. It is chiefly associated with mature and overmature fruit.

The principal objection to water-cored fruit is a shortened storage life, since water core in apples makes the fruit more disposed to mealy breakdown. Although affected fruit will recover in storage, our experience has shown that the normal storage period of apples is considerably shortened by the early development of mealiness or mealy breakdown. Water-cored areas near the main vascular bundles are commonly associated with the so-called "Jonathan breakdown."

Previous to the recent work of Brooks and Fisher (3) it was generally accepted that water core was caused by an excessive moisture supply, especially after periods of drouth. These investigations showed, however, that apples from trees under light irrigation developed more water core than apples from trees under heavy irrigation; also, that heavy irrigation followed by light gave more water core than light followed by heavy. Fruit exposed to direct sunlight during growth was more susceptible than that grown in shade, and mature and sunburned apples were higher in sap concentration and in susceptibility to water core. Water core was thus correlated with high sap concentration.

Still more recent investigations by Fisher et al. (6) have corroborated the above findings. These studies have shown that exposure of apples to artificial heat while on the tree resulted in more water core, and that apples so treated probably became water cored because of their high soluble sugar concentration which followed from a non-uniform conversion of starch. This being the case, the higher sugar concentration is the reason for

increase in turgor of certain cells and hence water cored tissue. Therefore, water core seems to be largely the result of excessively high temperature in the fruit while it is attached to the tree, and from this we have an explanation for the variable amounts of water core from season to season. Also, these conclusions help explain why water core varies with certain orchard practices, particularly those which directly affect the shading of fruit by the ratio of fruit to foliage, such as fertilizing, pruning, thinning and time of picking.

While it is impossible to recommend a means to control water core completely, certain orchard practices which help produce abundant and healthy foliage should be followed. These include good spraying practices, fertilizing, cultivating, irrigating and thinning. Picking at the proper maturity is the most practical method of control. In storage, water core apples recover more quickly in common storage or at temperatures higher than those used in cold storage. Marshall (10) reported 75 percent recovery on badly water cored Delicious apples during 11 weeks in cold storage. Large apples water core worse than small, but small apples recover better in storage.

BITTER PIT

Bitter pit is characterized by sunken, circular or nearly circular spots on the surface of the apple, which extend into the flesh as brownish elongated necrotic areas. Necrotic lesions of the flesh, however, are frequently present without any external markings, so that pitted apples may appear normal until used by the consumer. The names "bitter pit," "stippen" and "Baldwin spot" are sometimes used to designate this non-parasitic disease, but the term "bitter pit" is more descriptive. The spots are usually sunken or pitted and the affected tissue frequently tastes bitter. The pitted areas vary considerably in size and number and are most numerous on the blossom half of the apple. Bitter pit more nearly resembles hail injury than other spot diseases, in that the tissue is sunken, brownish in color, partially collapsed, dry and corky. Superficial spots are typically $\frac{1}{8}$ to $\frac{1}{4}$ inch in diameter and extend into the flesh to approximately the same distance. Deep seated lesions may extend to a depth of $\frac{1}{4}$ to $\frac{5}{8}$ of an inch into the flesh. Thus,

Fig. 14. Bitter Pit. Top: Cross section of bitter pitted apples (left to right): Rhode Island Greening, Baldwin, Rhode Island Greening.
Lower: Rhode Island Greening, Baldwin and Stayman. All specimens are severely affected. The disease differs from Jonathan spot in that the necrotic tissue is sunken and extends well within the apple pulp. Controlled by picking when fully mature and by low temperature.

only the outer portions of the apple are affected. (Fig. 14.) The color of the surface spots is usually brownish, but varies from gray-green to a reddish brown.

Although bitter pit seems to occur wherever apples are grown, it is more troublesome in some apple sections than others. Fortunately, relatively few important varieties are very susceptible to the disease. In the United States, Baldwin, Grimes Golden, Northern Spy, Rhode Island Greening and Stayman Winesap are particularly susceptible. In Iowa, Grimes Golden is the only important variety which is sometimes affected.

Considerable investigational work has given various theories as to the cause of bitter pit, and it is now generally conceded that its development is favored by conditions which result in irregularities of nutritional and moisture requirements during the growth of the fruit. Orchard management practices which give an even distribution of soil moisture, particularly during the later stages of ripening, are desirable in the prevention of bitter pit. Cultivation, fertilization, pruning, thinning and picking maturity all have an influence on bitter pit. Apples from young trees are more liable to pit than those from old, and large size fruit is more susceptible than small.

Bitter pit occurs on the tree, but makes most of its development on fruit in storage. Various investigations have shown that late picking is beneficial in checking the disease and that prompt storage is important. Fruit in common storage pits more severely than fruit in cold storage. Australian investigators, Carne et al. (4), have recently concluded that early picked fruit, which is high in starch, is more susceptible to pitting than late picked fruit. The same studies point to the conclusion that bitter pit is the result of uneven starch conversion (into sugar) in stored apples, which brings about an unbalanced osmotic relation between cells, since cells which lose starch late may have their cell sap concentration (acidity) increased, resulting finally in their death. It was pointed out that varieties which lose starch evenly throughout the apple were immune to the trouble. These conclusions seem to explain why maturity at picking and prompt storage play such an important role in the control of bitter pit, since these practices affect the starch content of apples.

FREEZING INJURY

Freezing injury is frequently confused with breakdown and other diseases of apples. A consideration of the symptoms of freezing injury and various storage diseases makes it easy to distinguish between them. Soggy breakdown has sometimes been confused with freezing injury, presumably because it occurs near the freezing temperature of apples.

Apples which have been slightly frosted in storage exhibit a characteristic mealiness and a slightly fermented taste. Fruit which has been frozen repeatedly, or for a long period, usually shows a browning of vascular tissue, as well as a mealy texture. The browning of the main vascular system is a distinctive characteristic of severely frozen apples. This characteristic has been described by Rose and Lutz (17). (Fig. 15.) Severely frozen fruit when permitted to thaw rapidly, becomes brownish, soft and mushy. Apples are readily bruised when frozen and should never be handled or transported while in this condition. (Fig. 26.) Frost injury in apples varies with the temperature, the length of exposure, the variety and the condition of the fruit. Alternate freezing and thawing cause a pro-

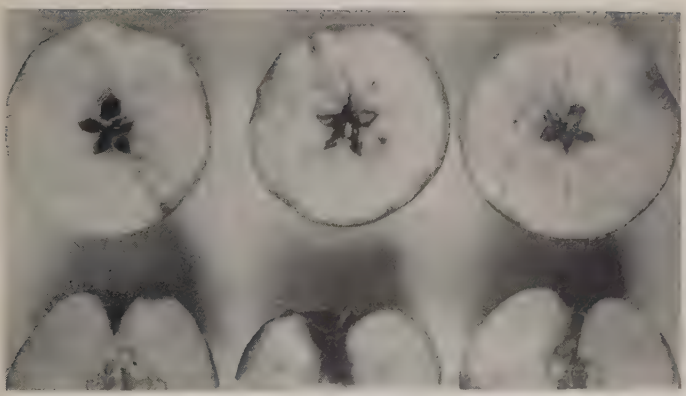

Fig. 15. Effect of freezing apples 48 hours. Left, Golden Delicious; center, Grimes Golden; right, Stayman Winesap. Note discolored vascular tissue radiating outward from the center. The tissue near the carpels in the pith region is also brown. Temperature 24-27° F.

gressive increase in injury. The cooling of apples below their freezing point without the formation of ice in the tissue does not cause any visible injury or softening of the fruit. According to Diehl and Wright (5), the freezing temperature of apples varies slightly with the variety and conditions under which they are stored, but is approximately 28.5° F.

When apples are severely frozen in storage they can often be salvaged and marketed. If the apples are thawed out gradually below 40° F. injury may not be apparent, except that the fruit may show a tendency to become mealy prematurely. When apples are severely frozen on the tree, or while in the orchard, they can under favorable climatic conditions be satisfactorily handled for future storage. Fruit in a frozen condition should not be picked nor moved until it has thawed out. Gradual thawing and care in handling are important. When the weather following the freezing of apples is cloudy and cool, little injury is apt to develop; but if it turns warm and clear following a hard freeze, severe injury may occur.

CORK AND DROUTH SPOT

Dry, brown, corky areas which have developed in apples while on the tree, apparently as a result of a deficiency in soil moisture, have been termed cork and drought spot. Dry hot

weather is conducive to this type of disorder, especially in regions where the soil is shallow or underlain with rock. "Cork," "drought spot," "York spot" and "crinkle" are terms which have been applied to this type of disease. All of these may not be identical, but they are at least similar and therefore may be considered together. The name cork is commonly used in describing brown dead tissue located deeply into the apple flesh, often near the core region, while the term drought spot is frequently applied to larger discolored corky areas nearer the surface. Fruit which is badly affected with cork or drought spot is not always sufficiently malformed to be easily culled out on the sorting table, and affected fruit sometimes gets into storage. This type of disease is of little importance, except in restricted districts where the soil is conducive to its development. In certain irrigated sections, however, an insufficient supply of water may increase the amount of cork and drought spot. It has been rarely observed in Iowa grown apples, although in recent years apple trees have suffered from lack of moisture in each of several seasons. (Fig. 16.)

Fig. 16. Drought spot on Northwestern Greening. Note brown, corky lesion with hollow center.

PENICILLIUM SOFT ROT

When sound apples having no skin breaks are stored, little loss from apple rots occurs. When an apple is affected by rot, careful examination will usually show the presence of some kind of skin puncture, and the probabilities are about 80 to 1

that the rot is the result of infection by Penicillium soft rot. While it is not the intent to include parasitic diseases of apples in this bulletin, the importance of the Penicillium soft rot fungus makes it desirable to give it special consideration.

The fungus disease, Penicillium soft rot, makes rapid development on ripe apples at ordinary temperatures. When apple tissue is affected it becomes soft, mushy and watery and is commonly covered with globules of blue spores (fig. 17); hence the names "soft rot" and "blue mold." Rotting fruit and fruit which has been in contact with affected fruit has a characteristic musty and disagreeable taste and odor which are associated with decaying apples. Penicillium soft rot is principally

Fig. 17. Penicillium soft rot. This parasitic disease causes more apples to decay in storage than any other storage rot. The bluish spores gain entrance through skin punctures and cause decay.

associated with ripe fruit and with apples stored at temperatures above that of cold storage. It consequently makes considerable progress in common storage fruit where the temperature is comparatively high early in the season. The spores gain entrance largely through stem punctures, although skin breaks caused by finger nails, basket and barrel bruises, basket staples and lids also result in infection. Soft rot is largely preventable by careful handling during picking and packing. Prompt storage at 32°-36° F. tends to hold the disease under control. Holding apples at the packing shed permits the spores to germinate, and after the rot starts it is difficult to check in storage. Wrapping the fruit in paper considerably lessens the spread of soft rot within the package, because the spores and germ tubes are

better confined to affected apples. The use of liners, pads and shredded paper in baskets and barrels tends to decrease the disease by lessening the amount of skin breaks and bruises. Under good commercial practice there is no excuse for Penicillium soft rot appearing to any great extent in the apple pack. It is a trouble which can be attributed almost entirely to careless handling of the fruit in the field or packing house.

SUGGESTIONS FOR HANDLING AND STORING APPLES

PICKING MATURITY

In the foregoing discussions we have indicated that maturity at picking time in apples is important in preventing losses from storage diseases. The determination of the correct stage of maturity at picking is consequently important. Unfortunately, there is no single test which is satisfactory as a measure of maturity. The apple grower must rely on his own skill and learn to judge maturity by such methods as are available. Most growers are able to determine when apples are ready for harvest by observation of certain changes in them toward the end of the ripening period. These include change in ground color, development of red surface, change in seed color, size of fruit and, most important, ease of separation from the tree. Changes in hardness of winter varieties while on the tree are difficult to measure with mechanical pressure testers. For example, it was found that Grimes Golden will soften only about one pound in 30 days. Softening of the fruit AFTER PICKING is very different and can be easily measured with a mechanical tester because apples soften very rapidly at ordinary temperatures.

The variation in the optimum picking date for apples in Iowa from year to year is small. For example, the optimum maturity date for Grimes in central Iowa has fallen between Sept. 21 and Sept. 26 each year for the past 9 years. Likewise, the optimum date for Jonathan has fallen between Sept. 30 and Oct. 5 over the same period. Although weather conditions vary greatly from year to year, it seems that maturity in apples is not necessarily governed by the weather alone, since the 9-year period during which observations were made includes some of the warmest and driest summers in 60 years according to the United States Weather Bureau records. Observing the calendar is therefore

Fig. 18. Speckled type of apple scald on Grimes. The russet colored spots are unevenly distributed over the surface of the apple and vary in size and regularity. The spots often center around the lenticels.

of some value in determining the approach of maturity in apples.

The importance of maturity at picking in the prevention of apple scald, mealy breakdown, water core and bitter pit already has been emphasized. Picking one week too early, for example, may mean a difference between profit and loss from the standpoint of scald and bitter pit control; while picking a week too late may result in much premature mealy breakdown or water core. Usually best results will be obtained by leaving the apples on the tree until they are fully mature and until packing and storage facilities are ready for operation. Due care should be taken, however, that apples do not become too ripe on the tree, since this may result in losses from dropping, especially if the weather is unfavorable.

Color is an important indication of correct picking maturity. Red apples are more popular than yellow, but in both, color intensity and completeness of covering are desirable. In general, the more color the better the quality of the fruit. Among red apples well colored specimens show scald less than poorly colored ones, shrivel less, keep longer and sell better. To obtain the maximum color without having part of the fruit become too mature it may be necessary to make two pickings, leaving the

poorer colored specimens to hang until full color has developed. Ultra deep color may be an indication of over-maturity. Late maturing varieties in Iowa, such as Stayman Winesap, Arkansas, Willow Twig and Winesap, do not ordinarily develop enough color until Oct. 15 or 20. Jonathan in Iowa can usually be left to color until the fruit is approximately 90 percent red, and such fruit will usually hold up well in cold storage until the first of May. Grimes Golden and Golden Delicious frequently are picked too early, and when they are, neither attractive color nor dessert quality is obtained. In general, the above statements hold equally well for other varieties.

STORAGE TEMPERATURE

The results of the experimental work on which this bulletin is based, extending over a period of 10 years, and confirmed by

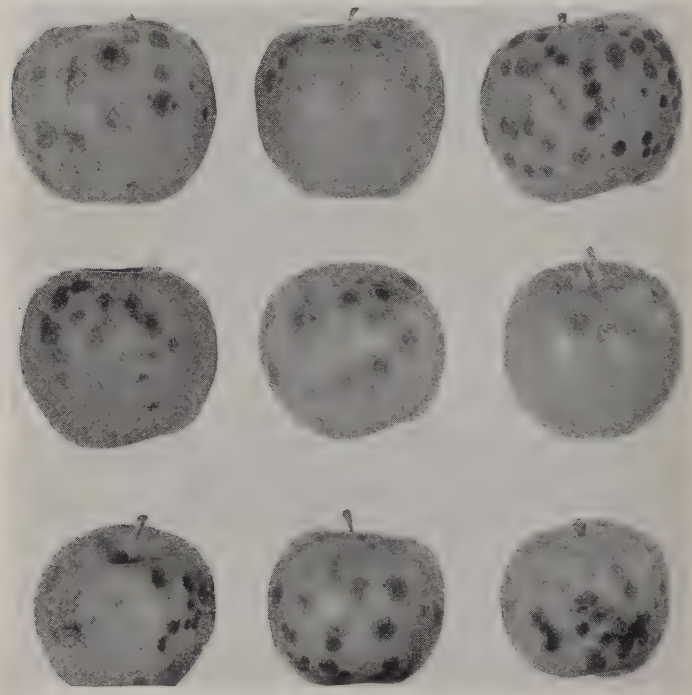

Fig. 19. Type of Jonathan spot centering around lenticels. Note concentric circles of discolored skin of various intensities. The spots increase in diameter. This type of Jonathan spot is common on fruit stored in air-cooled storages.

the work of investigators already quoted in these pages, indicate clearly that well sprayed, carefully handled apples picked at correct maturity keep better at temperatures of 35°-36° F. than at temperatures of 31°-32° F. Apples so stored develop better flavor and color, are not susceptible to soggy breakdown, and are more valuable on the market than apples stored at lower temperatures. Among the varieties on which these observations were made are Grimes Golden, Jonathan, Golden Delicious, Northwestern Greening, Arkansas, Delicious, Ben Davis, Winesap, Willow Twig and Stayman Winesap. Grimes Golden and Golden Delicious stored at 32° F. remain greenish in color, lack considerably in quality and appearance and are more difficult to sell on the market than the better conditioned fruit which results with storage at 36° F. In this respect poorly conditioned green fruit of these and similar varieties resemble certain pears which, when stored at low temperatures, never develop the characteristic flavor and yellow color desired by the consumer.

Temperatures 31° to 32° F. have long been recognized as standard storage temperatures. The reason that a change from these temperatures is recommended is that the practice of storing at 31° or 32° F. originated before modern spraying, harvesting and handling methods came into vogue. Consequently, prevention of decay from Penicillium soft rot and other fungi and prevention of apple scald were more important than any other considerations. Sound apples, undamaged in handling, seldom become infected with apple rot fungi. Apple scald is well controlled with the use of oiled wraps or shredded oiled paper; therefore, in modern cold storage practice, there is little need to store at minimum temperatures to prevent these troubles. It is recommended, however, that carelessly handled apples or those unprotected from scald by oiled paper be stored at 31° or 32° F.

Just why apples which are very ripe will keep much better in storage at 36° F. as compared with storage at 30° or 32° F. is not yet definitely known. Some information on this question, however, was obtained by a study of the respiration intensity of the apples carried out by Harding (7) on large samples collateral with the apples used in the experiment in table 7. He found the respiration activity to be highest in the fruit which

Fig. 20. Cross section of soft scald type of soggy breakdown on Jonathan apples. The affected tissue extends a slight distance into the pulp of the apple.

subsequently developed the greatest amount of soggy breakdown. That is, when the apples were transferred to cold storage during the period of high respiratory activity, much breakdown occurred. The respiration of the apples had considerably subsided after the fifth and sixth week of storage at 50° F., and then the fruit was no longer susceptible to this kind of breakdown. Pressure tests of the fruit also showed that the softening rate (therefore the ripening rate) had also slowed down after the sixth week. The results therefore indicated that apples may become very active physiologically soon after picking (unless the temperature is low), and that when such fruit is placed in storage it becomes very susceptible to soggy breakdown.

Fig. 21. The effect of storage temperature on soggy breakdown on Grimes. The three boxes shown were stored at temperatures (left to right) 30°, 32° and 36° F. All boxes were delayed two weeks at 50° F. before cold storing. The treatment resulted in much soggy breakdown, except at 36°. Compare with fig. 22.

Groups labeled "S"—free from breakdown.
Groups labeled "D"—breakdown fruit.

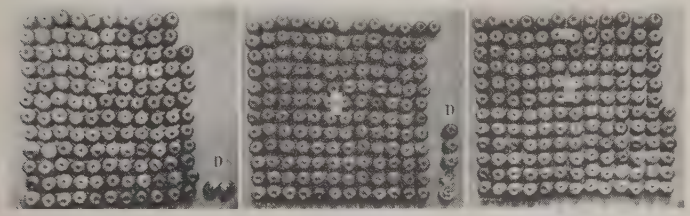

Fig. 22. The three boxes shown were stored at temperatures (left to right), 30°, 32° and 36° F. All boxes were delayed six weeks at 50° F. before cold storing. Compare with fig. 21.

The treatment made all the fruit practically immune to soggy breakdown but over-mature, and susceptible to scald, and premature mealy breakdown. The results illustrate the importance of temperature on the keeping of apples. The storage life of the apple is largely determined by the temperature to which it is subjected before and after placement in storage.

Groups labeled "S"—free from breakdown.
Groups labeled "D"—breakdown fruit.

HUMIDITY IN STORAGE

Of the conditions affecting apples in storage, humidity is probably second in importance only to temperature. The amount of moisture present in the storage room atmosphere is usually expressed in terms of relative humidity, and for cold storage temperatures (31°-32° F.) a relative humidity of 85 percent gives satisfactory results. With slightly higher temperatures, however, and with those such as ordinarily prevail in common storages, shriveling of apples will occur frequently, even with an 85 percent relative humidity. This is because the water holding capacity of the atmosphere is higher with the higher temperatures. In other words, the relative humidity alone does not give a complete picture of the conditions affect-

ing the loss of moisture from storage products; temperature must also be considered. For example, when apples are stored at 40° F. with a relative humidity of 85 percent, the loss of moisture will be more rapid than at 32° F. with the same relative humidity. It is therefore particularly important to maintain a high relative humidity with temperatures higher than 31°-32° F. With a temperature of 36° F. we have found a relative humidity of 90 percent more satisfactory than one of 85 percent, while a relative humidity of only 80 percent resulted in visible shriveling.

In common storage houses in Iowa the relative humidity during the first 6 weeks of storage is usually low (approximately 50-65 percent). The temperature of such storages for the same period is high (45°-55° F.). For this period in common stor-

Fig. 23. Soggy breakdown occurs on Golden Delicious, and the affected tissue may or may not be in contact with the skin. In this variety, however, the soft scald type of soggy breakdown is most common.

ages, then, we have two unfavorable conditions, i.e., low humidity and high temperature. Maintaining the proper humidity of common storages is therefore of primary importance, especially during the earlier part of the storage season when high temperatures prevail. Common storages with earth floors usually have higher humidities than such storages with concrete.

The fruit grower and the storage warehouseman can readily determine from the condition of the fruit whether the humidity is satisfactory. When visible shriveling of fruit is noticeable, more moisture should be supplied. This can be done by placing sphagnum moss, sand or other absorbent material under false floors and keeping the materials moist. Sprinkling the walls and floors of storage rooms frequently with water will also help increase humidity. At freezing temperatures common salt can be mixed with absorbent material to prevent freezing. Rela-

Fig. 24. Brown heart on English Newton Wonder apples. (Photograph, courtesy Kidd and West.) In contradistinction to soggy breakdown, the disease occurs well into the core region. Caused by accumulation of carbon dioxide within apple tissue. Controlled by storage ventilation.

tive humidity can be measured easily with the instruments designed for the purpose, but these for the most part are fragile, costly and require frequent standardization. When properly used, however, they give satisfactory results.

Apple varieties vary considerably in susceptibility to shriveling. The russet types and those sorts which are subject to

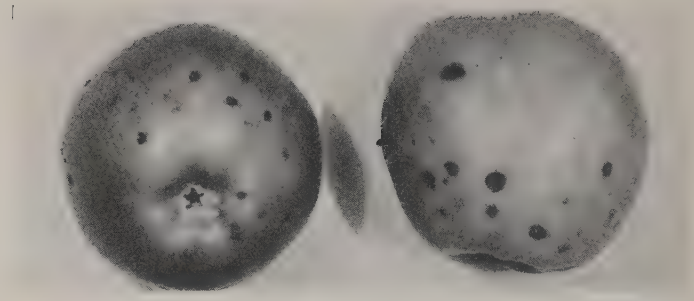

Fig. 25. External appearance of bitter pit. Note large sunken discolored areas. Left, Arkansas; right, Baldwin.

spray injury are more liable to shrivel than the more waxy kinds. Golden Delicious is more apt to shrivel than most other commercial varieties. (Fig. 27.) Specimens exhibiting spray injury usually shrivel worse than otherwise sound fruit.

THE STORAGE PERIOD OF APPLES

The length of the storage period of apples depends principally upon variety and storage conditions. It is assumed in this case that the storage period begins when the fruit is picked. From picking, the changes incident to ripening are greatly accelerated, and the rate of these changes depends principally on the storage temperature. Ripening proceeds rapidly at ordinary temperatures and slowly at cold storage temperatures; hence prompt storage is a requisite of long keeping.

Each variety has a normal storage life for any particular temperature. For example, the storage life of Grimes Golden at ordinary temperatures in the fall (65°-70° F.) is usually 1 month; in common storage (35°-55° F.) it is nearly 3 months; in cold storage (32°-36° F.) it is from 4 to 5 months. Late maturing varieties which ripen in cool weather keep better and for longer periods than early maturing sorts. Thus, every variety has a recognized storage limit for each particular kind of storage. In general, any variety in common storage should be marketed 2 months earlier than in cold storage. Advantage can be taken of these two types of storages to lengthen the period of marketing. For example, Stayman Winesap in common storage is ready for consumption throughout December

Fig. 26. Freezing injury. Top (left to right): Rhode Island Greening, Golden Delicious, Grimes Golden. These apples were severely bruised while in a frozen condition at a temperature of 22° F. to 28° F. Then they were subjected to a temperature range of 8-12° F. for several days and thawed out before photographing.

Lower: Cross sections of three Golden Delicious which were severely frozen. Note the corky dried out areas where the apples were severely bruised, and darkening of vascular tissue.

and January; in cold storage this variety can be marketed to better advantage in February and March. In a similar way the period of marketing may be increased for any other variety.

Large size fruit within a variety is usually not long keeping. Such fruit ripens rapidly and becomes mealy prematurely in storage. It is therefore good practice to market the larger apples early in the season. Attention has been called to the fact that certain apple disorders such as bitter pit, scald and freezing injury tend to shorten the period of storage by bringing

Fig. 27. Shriveled Golden Delicious. Loss of moisture takes place in apples which are held under conditions of low humidity and shriveling results. The disorder occurs rather commonly in air-cooled storages.

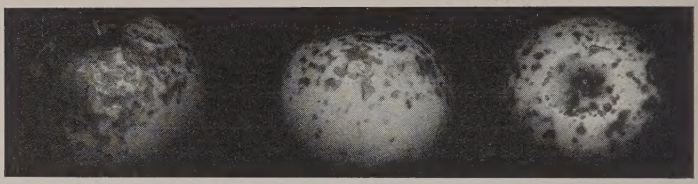

Fig. 28. Acid injury on Grimes. During recent years this pitted type of skin injury has appeared in storage in some instances on fruit which was previously treated for the removal of spray residues. It can be prevented by the adequate rinsing of the fruit after its treatment in the acid bath.

about prematurely a mealy condition. Likewise, storage at temperatures low enough to bring about soggy breakdown may considerably shorten the storage life of apples.

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